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IRRIGATION EXPERIMENTS ON APPLE-SPOT DISEASES[1]

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THE PROBLEM

The present paper deals with the effects of soil-water supply upon bitter-pit, Jonathan-spot, and certain other nonparasitic spot diseases of the apple (*Malus sylvestris*). It also includes notes upon the relation of the time of picking to the development of apple-spots in storage.

BITTER-PIT

HISTORICAL REVIEW

Bitter-pit was first described by Wortmann (*22*)[2] under the name "*Stippen.*" It has been frequently discussed in the publications of the State Experiment Stations under the name "Baldwin-spot" and was referred to in the Nineteenth and Twentieth Reports of the New Hampshire Experiment Station as "fruitpit." Lewis (*8*) and Allen (*1*) apparently used the term "fruitpit" to refer to the troubles discussed later in this paper under the name "cork," and McAlpine (*9–12*) apparently included cork and also drouthspot under the name "bitter-pit."

Various explanations have been offered as to the cause and nature of bitter-pit. Wortmann (*22*) reported that the disease was due to abnormal transpiration conditions and that varieties of apples in which the water was conducted most readily from the deeply seated cells to replace that lost by transpiration were least susceptible.

Sorauer (*19, p. 80*) thought that the pits were produced by rupturing of the cells during the process of swelling. In a later publication (*20, p. 116-169*) he stated that the disease was worst on porous dry soils and suggested that the pits were produced by an overrapid maturing of certain cell groups resulting from the checking effect of drouth upon the accumulation of organic material.

Evans (*5*) reported that the disease was due to a bursting of cells in the apple tissue that resulted from the sudden checking of transpiration at night while the root action of the tree remained vigorous.

[1] Studies on Fruit Rots and Spots: III.

[2] Reference is made by number (italic) to "Literature cited," p. 136–137.

Ewart (*6*, *7*) concluded that the disease was the result of local poisoning and mentioned spray materials and the toxic salts of the soil as possible causes.

White (*21*) considered that the disease was the result of the poisoning effects of arsenical compounds and other spray materials.

McAlpine (*9*–*12*) thought that the disease was produced by a shortage of water in the affected tissue and that the condition might be brought about either by transpiration exceeding the water supply or by the growth of the pulp tissue being too rapid to allow time for the formation of the new vascular tips needed to supply it with water. He found that there was slightly less of the disease on trees receiving two irrigations than on those receiving one.

DESCRIPTION OF BITTER-PIT

Bitter-pit makes its first appearance as water-soaked bruiselike spots on the surface of the apple. The epidermal tissue is at first entirely normal, the spotted effect being due to the breaking down of cells in the subepidermal region. The spots soon become depressed into rather definite pits, 2 to 6 mm. in diameter, hemispherical in shape, and fairly regular in outline. They develop a higher color than the surrounding surface of the apple, becoming a deeper red than the adjacent tissue when occurring on the colored portion of the fruit and a darker green when on the lighter parts (Pl. 2, A). As the disease advances farther, the spots take on a brownish color owing to the dead pulp cells beneath the epidermal layers, and in late stages of the trouble the affected area may entirely lose its normal color, becoming a deep brown (Pl. 3, A). The diseased tissue is dry and spongy, the cells are collapsed but still full of starch, and the cell walls show no sign of thickening or disintegration. The affected tissue often has rather a bitter taste, and this together with the sunken nature of the spots has given rise to the term "bitter-pit."

The pits are usually associated with the terminal branches of the vascular bundles, and the surface spotting is often accompanied by a browning of the vascular tissue deeper in the fruit, giving the appearance of numerous brown spots in the flesh when the apple is cut (Pl. 2, B). This internal browning is especially common in the tissue within a centimeter of the surface of the apple. While the internal browning and surface pitting are commonly associated, either may occur without the other.

Bitter-pit is often confined to the calyx half of the apple. Baldwin, Northern Spy, Grimes, Jonathan, and Yellow Bellflower are especially susceptible to the disease; and Rome Beauty and Winesap are fairly resistant; but almost all varieties are sometimes affected.

Bitter-pit is very similar in appearance to rosy-aphis stigmonose, but the latter disease is not accompanied by a browning of the vasculars and the subepidermal tissue has a firmer texture and a darker color than is the case with bitter-pit. Stigmonose is found only on limbs that

were infested with aphids earlier in the year, and the spots usually appear several weeks before picking time, while bitter-pit is rather evenly distributed over the tree and is found only on mature or nearly mature fruit. Bitter-pit can be distinguished from fruitspot by the fact that with the latter disease there is an almost entire absence of subepidermal browning, and the spots have an irregular outline and a flecked or speckled appearance.

EXPERIMENTAL WORK

The writers were convinced by earlier investigations that bitter-pit was not due to fungi or bacteria. They had frequently seen unsprayed fruit that was seriously affected with the disease, thus making the theory that spray materials were responsible for the trouble seem entirely untenable. Drouth had frequently been mentioned as a cause of bitter-pit, and several writers had suggested an excessive or uneven water supply as a possible cause, but little experimental data had ever been furnished in support of any of these theories. The question of the influence of soil-water supply seemed to the writers to be an extremely important one, and a series of experiments were started to determine the effect of irrigation upon the disease.

The work has been located at Wenatchee, Wash. The climate of the section is arid, but little precipitation occurring from April till October, thus making the trees almost entirely dependent upon irrigation for their soil-water supply during the growing season. Except where otherwise mentioned, the water was applied by the furrow method (Pl. 4, A). The contrasts in the amount of water on the different plats were secured by varying the frequency and duration of the irrigations and, in some cases, by differences in the number of furrows supplying water to the row and by variations in the head of water at the flume.

The amount of water in the soil was determined by means of samples taken with a soil auger. In the beginning of the work samples were taken at depths of 6, 18, 30, 42, and 54 inches—that is, from the middle of each of the first 5 successive feet of soil—but in the final experiments, as reported later, samples were taken only from the one or two depths that seemed most important in determining the condition under which the tree roots were working in the particular orchard.

Some difficulty was found in securing samples that represented the average moisture conditions of the tree row. The lateral movement of soil water is very slow, resulting in considerable contrast between the amount of moisture beneath the irrigation furrow and a few feet from it, especially in the upper layers of the soil. Samples were usually taken at a distance from the furrow equal to one-fourth the space between the furrows, thus securing soil from a point midway between the wettest and dryest areas. The plan of sampling was always the same for the different plots of a particular orchard. Samples were taken at intervals of 7 to 10 days, and usually just before and 1 or 2 days after an irrigation, thus obtaining a record of the extremes in soil-water conditions.

As soon as obtained, the samples were transferred to tin cans with tightly fitting lids, and the cans immediately closed. The weight of the fresh soil sample was determined and a second weighing made after the soil had been reduced to constant weight in a drying oven, the difference between the two weighings being taken as the moisture content of the sample. The percentage of saturation was determined by comparing the moisture content of the sample with the total water-holding capacity of the soil. In the experiments of 1914 and 1915 the latter was secured by taking the average water-absorbing capacity of a large number of samples, but in 1916 saturation tests were made on each soil sample.

Notes were taken on the amount of bitter-pit at picking time, and later notes were taken to determine the increase in storage. The apples were cut open at the time of the last note-taking and a record made of the amount of internal browning. An apple was counted as affected with bitter-pit if it had either internal or external evidence of the disease, but very few apples showed internal browning that did not also have the external pitting.

EXPERIMENTS ON GANO APPLES IN 1914

The irrigation experiments were begun in 1913. The results of the first season were of little value, since the main trouble in the experimental orchards was found to be stigmonose instead of bitter-pit. In 1914, the data from the most promising orchard were lost on account of mistakes of the picking crew, but some interesting contrasts were obtained in an orchard of Gano apples. The trees in the latter orchard were 11 years old and thrifty; the soil was a volcanic ash, uniform in texture to a depth of 6 feet. The orchard had been under clean cultivation but at the time of the experiments was sown to vetch. There were four trees in each plat. The soil-moisture condition for the season is shown in figure 1. All of the plats became quite dry the middle of August on account of trouble with the irrigation canals.

TABLE I.—*Percentage of bitter-pit on Gano apples in 1914*

Plat No.	Irrigation treatment.	Total number of apples.	Percentage of apples of following sizes:					Percentage of bitter-pit.
			3¾ to 4 inches.	3½ to 3¾ inches.	3¼ to 3½ inches.	3 to 3¼ inches.	2¾ to 3 inches.	
1	Heavy throughout season.....	129	2.7	25.2	27.0	36.6	8.5	7.0
2	Medium throughout season.....	152	.8	18.8	30.6	41.9	7.9	2.6
3	Light throughout season.....	176	.0	7.0	30.6	39.9	22.5	2.3
4	Medium till Aug. 1, then light...	144	.6	21.9	23.9	41.0	12.6	.0

The crop was quite heavy, averaging about 25 bushels per tree. There was no bitter-pit on the fruit at picking time. Five boxes of apples from each plat were placed in cold storage and held for three months. Tab e I gives the results of notes taken at the end of this storage period.

The results make it evident that heavy irrigation favored bitter-pit, and also increased the size of the apples. It can be seen that there is

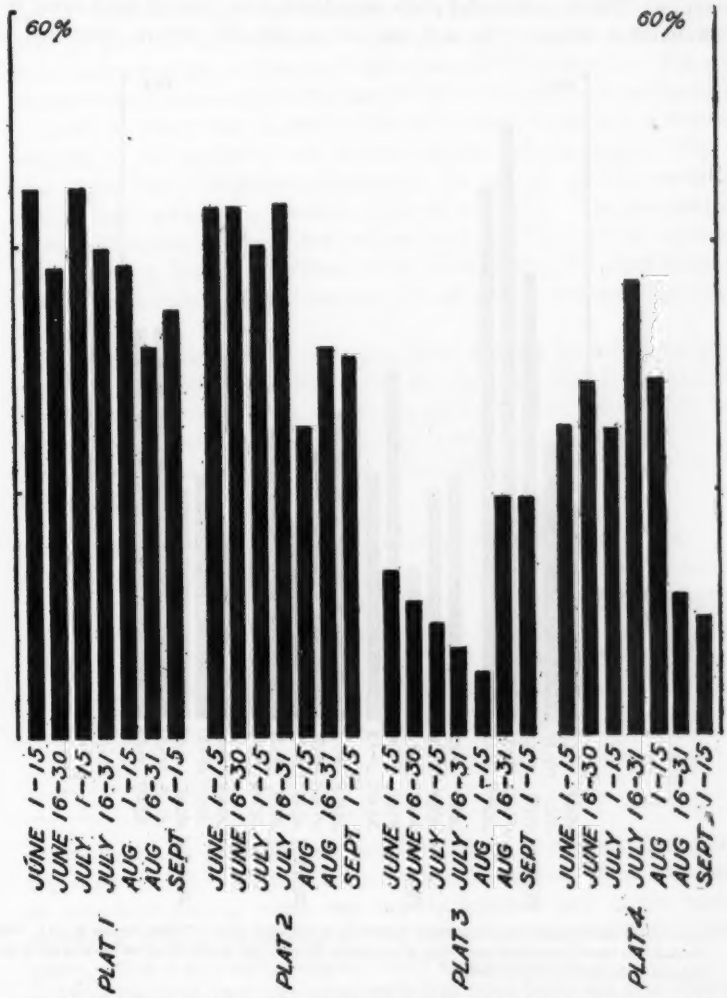

FIG. 1.—Diagram showing the soil-moisture conditions in irrigated plats of Gano apples in 1914. The results show the average percentage of saturation for each half month based on the average of soil samples at depths of 24 and 36 inches.

a very close relation between the size of the apple and the amount of the disease, but there is hardly sufficient parallelism to justify the conclusion that the increase in bitter-pit is entirely due to increase in size.

EXPERIMENTS ON GRIMES APPLES IN 1915

Similar irrigation experiments were carried out in 1915 on Grimes apples. The experimental plats were located on bottom land along the Wenatchee River. The soil was of an alluvial nature composed of

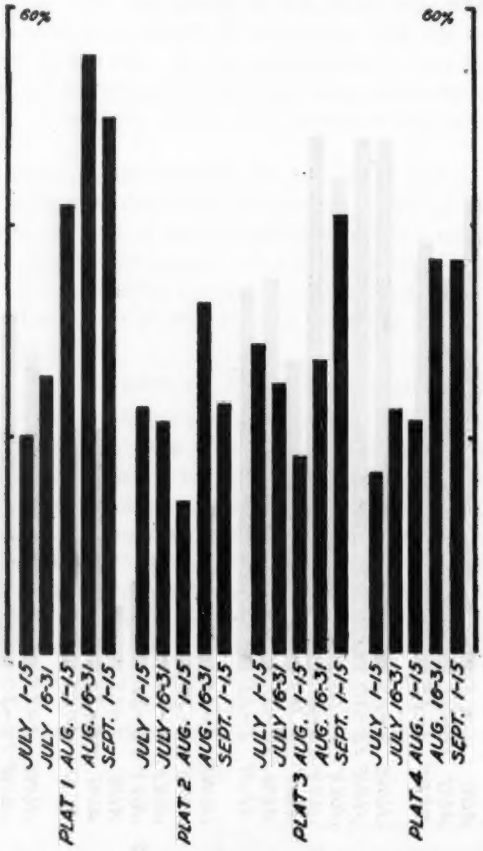

FIG. 2.—Diagram showing the soil-moisture conditions in irrigated plats of Grimes apples in 1915. The vertical bars show the average percentage of saturation for each half month based on the average of soil samples at depths of 24 and 36 inches.

medium heavy sandy loam with considerable clay and was uniform to a depth of 3 feet. It was kept under cultivation in the tree row. The trees were 5 years old and making a vigorous growth. They were quite uniform in size and vigor and satisfactory in every respect for comparative experiments. Three trees were used in each plat. The fruit was

kept practically free from stigmonose by means of a late dormant spray of lime-sulphur and nicotin sulphate.

The irrigation of the orchard was not satisfactory because of a shortage of water resulting from trouble with the canals. A cloudburst on July 26 gave an indiscriminate watering to all the plats. Irrigations were made according to plan on August 24 and September 12. The soil moisture conditions for the latter part of the season are shown in figure 2.

It will be noted that in spite of the unfavorable conditions a decided contrast in soil moisture was secured on the different plats. Plat 1 was given heavy irrigation throughout the season; plat 2, medium; plat 3, light; and plat 4, medium, followed by heavy. The percentages of soil saturation given do not indicate any decided contrast between plats 2 and 3, but the condition of the trees in the two plats made it very evident that a distinct contrast in soil-water conditions had been secured.

The yield in the orchard was light, being about a bushel to the tree. The fruit was gathered on September 22, about 10 days later than the average commercial picking of Grimes apples in that section. It was placed immediately in cellar storage at a temperature of about 50° F. Notes were taken on bitter-pit seven days later. The results are shown in Table II.

TABLE II.—*Percentage of bitter-pit on Grimes apples. September 29, 1915*

Plat No.	Irrigation treatment.	Total number of apples.	Percentage of apples affected with bitter-pit.		
			Windfalls.	Picked fruit.	Total.
1	Heavy	299	90	43	56
2	Medium	222	30	17	25
3	Light	156	36	14	23
4	Medium till Aug. 24, then heavy	175	77	49	59

The contrasts are quite striking and make it evident that heavy irrigation tended to increase the amount of bitter-pit. It is interesting to note that plat 4, which was heavily irrigated late in the season, showed a greater percentage of the disease on the picked fruit than plat 1, which was heavily irrigated early as well as late.

All of the fruit that was apparently free from bitter-pit was returned to cellar storage and notes were taken again on November 9. The results are given in Table III. All of the percentages but those in the last column are based on the number of apples returned to storage and not on the number in the original yield from the plats.

TABLE III.—*Percentage of bitter-pit on Grimes apples in storage. November 9, 1915*

Plot No.	Irrigation treatment.	Total number of apples.	Percentage of apples of the following sizes.		Percentage of apples that developed bitter-pit from Sept. 29 to Nov. 9.			Total percentage of bitter-pit developed by Nov. 9.
			Larger than 2⅝ inches.	2⅝ inches and smaller.	Apples larger than 2⅝ inches.	Apples 2⅝ inches and smaller.	Total.	
1	Heavy	132	81.8	18.2	63.9	4.2	53.0	79
2	Medium	166	92.2	7.8	48.4	.0	44.6	59
3	Light	106	83.0	17.0	33.7	11.0	29.2	52
4	Medium till Aug. 24, then heavy	72	98.6	1.4	63.4	.0	62.5	84

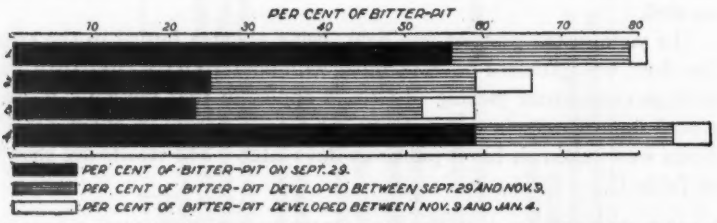

FIG. 3.—Diagram showing the amount of bitter-pit on Grimes apples in 1915. The black portions of the bars indicate the percentage of apples affected with bitter-pit one week after picking; the shaded portions, the amount developed between September 29 and November 9; and the white portion, the amount between November 9 and January 4. All of the percentages are based on the number of apples at the beginning of the experiment. See figure 2 for soil-moisture conditions.

A study of Table III shows that nearly all of the bitter-pit occurred on the apples that were larger than 2⅝ inches. The percentages in the next to the last column show that the contrasts in bitter-pit on the stored samples were similar to those found a week after picking, and indicate the importance of orchard conditions in determining the susceptibility of the fruit in storage. These percentages are estimated on the basis of the sound apples left on September 29. If the original number of apples were taken as a base in estimating percentages, these contrasts would partially disappear, as is shown in figure 3; but this would be an unfair comparison, so far as determining behavior in storage is concerned, as a large number of the apples had already been eliminated from the experiment. The last column in Table III shows the total amount of bitter-pit to November 9, estimated on the basis of the original number of apples.

The sound fruit from the above experiment was returned to cellar storage and a third set of notes taken on January 4, the fruit being cut open at this time to determine the amount of internal streaking or browning. But very few specimens of bitter-pit were found, and these gave but little contrast between the fruit from the different irrigation plats.

The results obtained on Grimes apples in 1915 are shown in graphic manner in figure 3. The contrasts for the season are similar to those obtained on September 29.

EXPERIMENTS ON GRIMES APPLES IN 1916

In 1916 the experiments were continued in the Grimes orchard described above. Five trees were included in each plat. It was possible

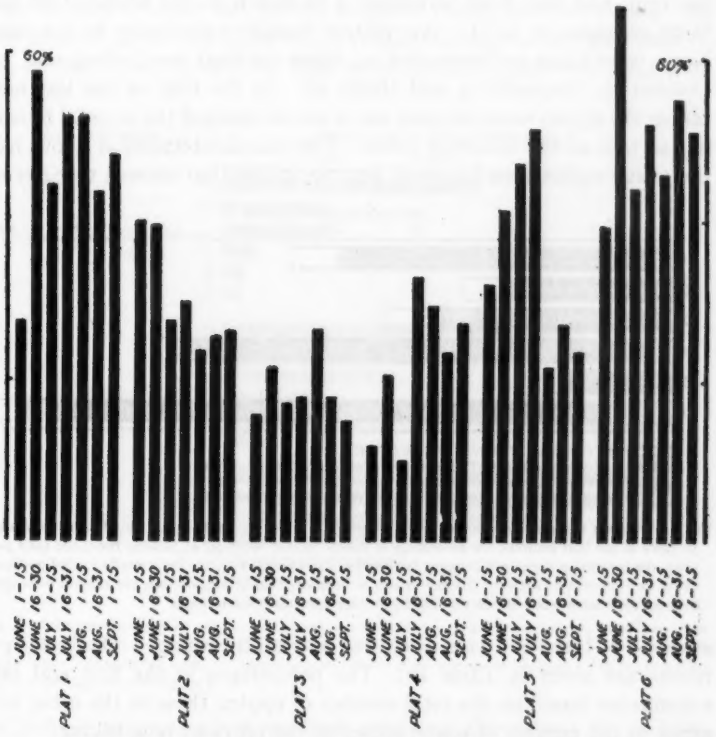

FIG. 4.—Diagram showing soil-moisture conditions in irrigated plats of Grimes apples in 1916. The results show the average percentage of saturation for each half month based on the average of soil samples at depths of 24 and 36 inches. Plat 1 received heavy irrigation throughout the season; plat 2, medium; plat 3, light; plat 4, medium till late in July, then heavy; plat 5, medium in June, heavy in July, and light in August and September; and plat 6, heavy throughout, with the exception of a sudden drop to medium in July.

to carry out the irrigation schedule much more satisfactorily than in the preceding year. The soil-moisture conditions for the season are shown in figure 4.

The fruit on plat 3 was noticeably smaller than that on the other plats as early as August 1, and by the close of the season the effects of irrigation were quite evident in the size of the fruit from the various plats. At picking time the fruit on plat 3 was found to be somewhat riper and more highly colored than that on the other plats. The apples were picked

on September 16. The crop was uniform and quite heavy, making it possible to secure approximately 2 bushels from each tree for storage.

The fruit was placed in cellar storage in open packages. Hygrothermograph records showed that from September 19 to October 18 the temperature of the cellar averaged 55° F., and the relative humidity approximately 55 per cent; that from October 18 to November 9 the average temperature was 48° F. and the average relative humidity 68 per cent, and that from November 9 to March 20 the temperature was fairly constant at 35° F., the relative humidity averaging 80 per cent. Notes were taken on September 19, when the fruit was picked, and on October 18, November 9, and March 20. At the time of the last note taking the apples were cut open and a record made of the internal browning as well as the bitter-pit spots. The vascular bundles of about half the pitted apples were browned, but the apples that showed no external

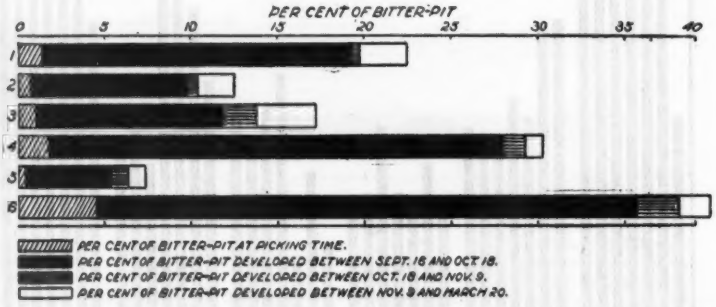

FIG. 5.—Diagram showing the amount of bitter-pit on Grimes apples in 1916. The diagonally shaded portions of the bars indicate the percentage of apples having bitter-pit at picking time; the solid portions, the percentage developed between September 19 and October 18; the horizontally shaded portions, the amount developed between October 18 and November 9; the white portions, the amount developed between November 9 and March 20. See figure 4 for soil-moisture conditions.

evidence of bitter-pit were free from internal browning. The bitter-pit results are given in Table IV. The percentages in the first and last columns are based on the total number of apples, those in the other columns on the number of sound apples at the previous note taking.

TABLE IV.—*Percentage of bitter-pit on Grimes apples*

Plat No.	Percentage of apples affected with bitter-pit.				
	At picking time, Sept. 19.	Developed between Sept. 19 and Oct. 18.	Developed between Oct. 18 and Nov. 9.	Developed between Nov. 9 and Mar. 20.	Total.
1	1.5	19.8	0.8	3.3	23.0
2	1.0	9.8	1.0	2.0	12.7
3	.7	12.1	2.0	4.1	17.6
4	1.3	28.7	1.5	2.0	31.1
5	.4	5.3	1.6	.6	7.6
6	4.1	35.2	5.5	3.2	40.8

A study of the table shows that nearly all of the disease developed during the first month of storage. The contrast between the plats, however, makes it evident that the development of the disease was largely determined by orchard conditions. The apples from the heavily irrigated plats were in all cases more susceptible to bitter-pit than those from the lightly irrigated ones. The amount of disease was much greater on plats 4 and 6, which were irrigated heavily only late in the season, than on plat 1, which was heavily irrigated throughout the season. It was less on plat 5, which had heavy irrigation followed by light, than it was on plat 3, which received light irrigation throughout the season, or

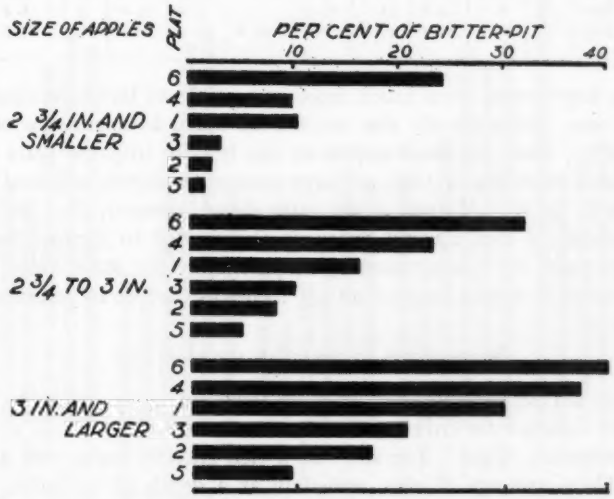

FIG. 6.—Diagram showing the relation of the amount of bitter-pit to the size of apples. The bars show the amount of disease on the different plats and are grouped according to size of apples. It will be noted that heavy irrigation increased the disease as much on the small fruit as on the large. For the irrigation of the different plats see figure 4.

on plat 2, which received medium irrigation throughout the season. The results indicate that the character of the irrigation during the last weeks in which the apples are on the trees largely determines the amount of bitter-pit developed in storage.

The total amount of bitter-pit for the season is shown in graphic manner in figure 5. All of the percentages are based on the original number of apples.

In the note taking of October 18 the apples were graded according to size, and the record on bitter-pit made accordingly. The results are given in Table V and figure 6.

TABLE V.—*Percentage, according to size, of Grimes apples affected with bitter-pit. October 18, 1916*

Plat No.	Total number of apples.	Percentage of apples of various sizes.					Percentage of apples of various sizes affected with bitter-pit.					Total percentage of bitter-pit.
		3½ to 3¾ inches.	3¼ to 3½ inches.	3 to 3¼ inches.	2¾ to 3 inches.	2¾ inches and smaller.	3½ to 3¾ inches.	3¼ to 3½ inches.	3 to 3¼ inches.	2¾ to 3 inches.	2¾ inches and smaller.	
1	776	0.4	10.8	30.8	37.9	20.1	100.0	52.4	20.9	13.6	10.9	19.8
2	775	.....	6.4	26.5	50.2	16.9	.....	36.0	13.6	6.9	2.3	9.8
3	879	.1	10.3	28.3	48.8	12.5	100.0	14.5	26.7	9.6	3.6	12.1
4	560	.....	12.5	38.6	39.1	9.8	.....	54.3	31.0	23.3	9.1	28.7
5	690	.....	6.7	24.8	45.1	23.4	.....	7.0	15.2	5.1	1.2	5.3
6	715	.4	20.7	31.2	40.8	6.9	100.0	31.9	50.0	31.5	24.5	35.2

The large apples were much more susceptible to bitter-pit than the small ones, but evidently size can not be taken as a measure of susceptibility, since the small apples on the heavily irrigated plats often developed more disease than the large ones on the lightly irrigated ones. (Table V; fig. 6.) A study of the table shows, however, that the same soil conditions that favored bitter-pit also tended to increase the size of the fruit, the plats standing in practically the same order as to percentage of apples larger than 3¼ inches as they do in percentage of bitter-pit.

EXPERIMENTS ON JONATHAN APPLES IN 1915

Irrigation experiments were made on Jonathan apples similar to those already reported on Grimes. The work was carried out in an orchard at Wenatchee, Wash. The soil was a rich gravelly loam, with a considerable percentage of clay, underlain at a depth of 16 inches with a layer of medium fine gravel. For several years previous to the beginning of the experiments the orchard had been heavily manured with slaughterhouse refuse, and during the time of the experiments it was kept in alfalfa. The trees were 6 years old, and there were 5 trees in each plat. The experiments were begun in 1915. Breaks in the irrigation canals at various times and a rainstorm on July 26 made it impossible to secure much contrast in the different plats before the first of August. All the trees but those of plat 1 were extremely dry the latter part of June and the first half of July. A further report of this condition is given later in this paper under the head "Drouthspot." There was a shortage of water several times in August, plat 5 suffering severely from drouth at this time and finally losing more than 75 per cent of its foliage and considerable of its fruit (Pl. 4, B). Plat 3 suffered from drouth the latter part of August, but no defoliation occurred. Plat 2 was practically as wet as plat 1 during the latter part of July and first of August, but became quite dry about the middle of August. The moisture conditions for the season are given in figure 7.

The first picking was made on September 3, when the apples were rather green, a second on September 17, when they were right for commercial picking; and a third, October 1 when the fruit was dead ripe. In most cases a bushel of apples was secured from each tree at each picking. There was practically no bitter-pit on the fruit at picking time. The apples were placed in cellar storage at an average temperature of about 47° F., and notes were taken November 10. The results are given in Table VI.

All apples more than 2⅝ inches in diameter were counted as large, and the others as small. There was little contrast as to size in the fruit

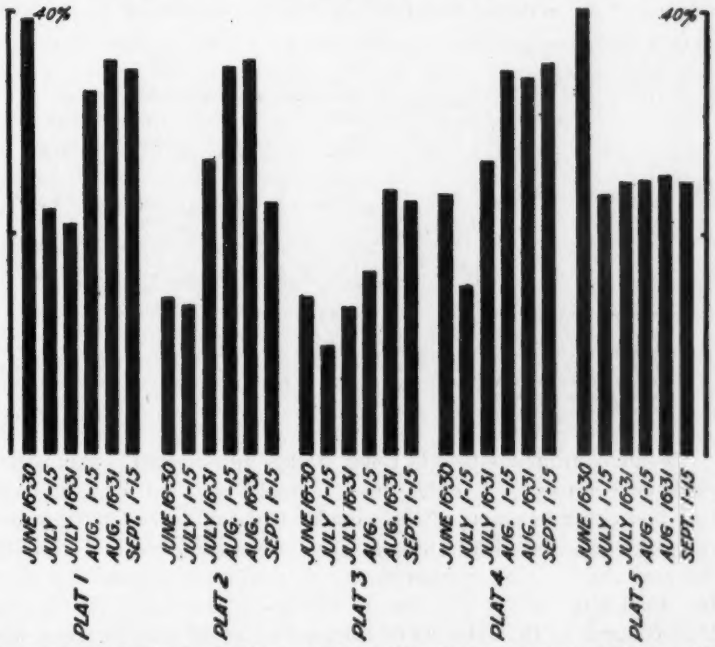

FIG. 7.—Diagram showing the soil-moisture conditions in irrigated plats of Jonathan apples in 1915. The average percentage of saturation is given for each half month and is based on soil samples taken at a depth of 16 inches. Plat 1 was to receive heavy irrigation throughout the season; plat 2, medium; plat 3, light; plat 4, medium in August, then heavy; and plat 5, heavy till August 1, then light. The schedule was followed as closely as the water supply would allow.

of the different pickings, and all three were combined to obtain the data given on size.

The large apples again have much more bitter-pit than the small ones. The apples of the first picking had more than twice as much bitter-pit as those of the second and those of the second several times more than those of the third. It might be suggested that a part of this contrast should be attributed to the fact that the earlier pickings had been in storage longer, but the later development of the disease in storage gives no support for this hypothesis. The more mature fruit was apparently much less sus-

ceptible to the disease. A study of the total bitter-pit as given in the last column of Table VI shows effects from irrigation similar to those obtained on Grimes apples. The fruit from the trees receiving medium irrigation followed by heavy irrigation late in the season had the most bitter-pit, and that from the trees irrigated heavy both early and late the next in amount. As has already been mentioned, the contrast between plats 1 and 2 in the amount of irrigation was not as great as intended; the latter, however, received less water and had less pit than the former. Plats 2 and 5 had but little bitter-pit, even on the large apples. The fruit from plat 2, however, was of an inferior quality on account of the sunscald that resulted from the defoliation of the trees.

TABLE VI.—*Percentage of Jonathan apples affected with bitter-pit. November 10, 1915*

Plat No.	Irrigation treatment.	Percentage of apples of following sizes.		Percentage of apples affected with bitter-pit.								
				First picking.		Second picking.		Third picking.		Total.		
		Larger than 2¾ inches	2¾ inches or smaller.	Apples larger than 2¾ inches	Apples 2¾ inches or smaller.	Apples larger than 2¾ inches	Apples 2¾ inches or smaller.	Apples larger than 2¾ inches	Apples 2¾ inches or smaller.	Apples larger than 2¾ inches	Apples 2¾ inches or smaller.	Large and small
1	Heavy	91.9	8.1	32.9	22.7	15.0	16.7	4.0	22.2	18.5	22.0	18.6
2	Medium	82.4	17.6	32.5	5.9	11.7	2.0	1.3	.0	16.1	2.3	13.6
3	Light	66.9	33.1	13.7	8.2	5.4	1.4	.0	.0	5.9	3.8	5.7
4	Medium, followed by heavy	92.9	7.1	44.4	16.7	23.0	8.3	1.9	.0	25.8	9.1	24.6
5	Heavy, followed by severe drouth	49.8	50.2	4.5	4.4	.0	.0	.....	.....	3.4	3.3	3.4

The above fruit was held in cellar storage and a second examination made on February 7. At this time the apples were cut open, and any that had either browning of the vascular tissue or surface pitting were counted as affected with bitter-pit. The results are given in Table VII, the percentages being computed on the number of apples that were free from bitter-pit at the time of the last note-taking. There was little contrast in the amounts of disease on the different pickings, and the three are considered together.

TABLE VII.—*Percentage of bitter-pit on Jonathan apples. February 7, 1916*

Plat No.	Irrigation treatment.	Percentage of apples that developed bitter-pit in storage from November 10 to February 7.			Total percentage for season.
		Large Apples.	Small Apples.	Large and small apples.	
1	Heavy	7.6	5.5	7.4	24.6
2	Medium	2.1	.6	1.3	14.7
3	Light	3.6	1.9	3.3	8.8
4	Medium, then heavy	1.9	.0	1.6	25.8
5	Heavy, then very light	.9	1.2	1.0	4.3

But little bitter-pit had developed on any of the apples during the three months of cellar storage. This may have been because the susceptible apples had already been eliminated, or may have been due to the fact that the apples were in an open package and finally became slightly shriveled. The relative amounts of disease on the apples from the various irrigation plats is little different from that given in Table I. The results for the season are shown in the last column of Table VII and also in figure 8.

EXPERIMENTS ON JONATHAN APPLES IN 1916

The bitter-pit experiments were continued in 1916 in the Jonathan orchard already described. The irrigation conditions were much more

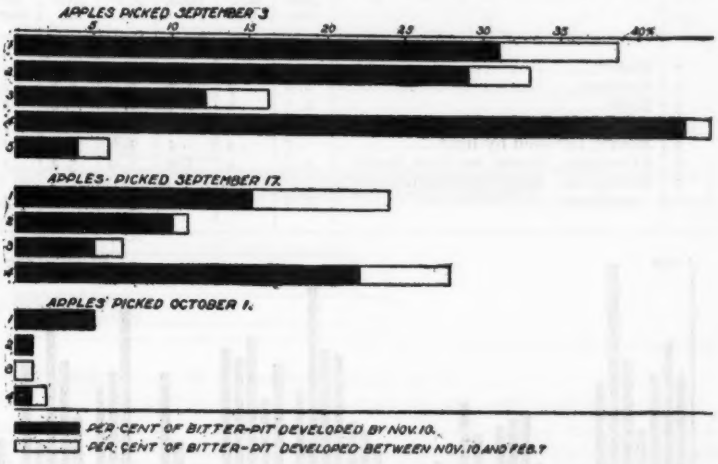

FIG. 8.—Diagram showing the amount of bitter-pit on Jonathan apples in 1915. The solid portions of the bars indicate the percentage of apples affected with bitter-pit on November 10, the white portions the percentage developed between November 10 and February 7. All of the percentages are based on the number of apples at the beginning of the experiment. See figure 7 for soil-moisture conditions.

satisfactory than in 1915. The percentages of soil saturation maintained on the different plats are shown in figure 9.

All of the trees were in vigorous condition except those of plat 3, which were apparently suffering from the effects of the drouth of 1915. The apples of this plat were very highly colored, while those of plats 5 and 7 were rather low in color. The first picking was made on September 22 and a second on October 2. The apples of the first picking were undercolored and immature, while those of the second were well colored and suited for commercial picking. Approximately 3 bushels of apples were saved from each plat in the first picking, and approximately 2 bushels from each in the second, and placed in cellar storage. There was no bitter-pit on the apples at picking time and none had developed by October 24. The results obtained from notes taken on November 14

and on March 18 are given in Table VIII. From the time of the storage of the fruit till November 14 the average temperature of the cellar was approximately 50° F., and the average relative humidity about 61 per cent. From November 14 to March 18 the temperature averaged 38° F., and the relative humidity 80 per cent.

TABLE VIII.—*Percentage of Jonathan apples affected with bitter-pit in 1916*

Plat No.	Irrigation treatment.	Percentage of apples affected with bitter-pit.					
		Nov. 14.			Mar. 18.		
		First picking.	Second picking.	Total.	First picking.	Second picking.	Total for year.
1	Heavy	3.0	0.0	1.5	4.9	2.3	3.5
2	Medium	2.6	.7	1.7	2.9	1.7	2.3
3	Light	1.5	.0	1.3	2.6	.0	2.2
4	Medium, followed by heavy	9.4	.0	5.6	11.1	2.2	7.5
5	Heavy, followed by light	.5	.4	.4	1.8	.3	1.4
6	Alternating, heavy, medium, heavy	1.3	.4	1.0	3.0	5.2	3.7
7	Alternating, heavy, medium, heavy, medium	2.9	.0	1.6	5.8	2.2	4.2

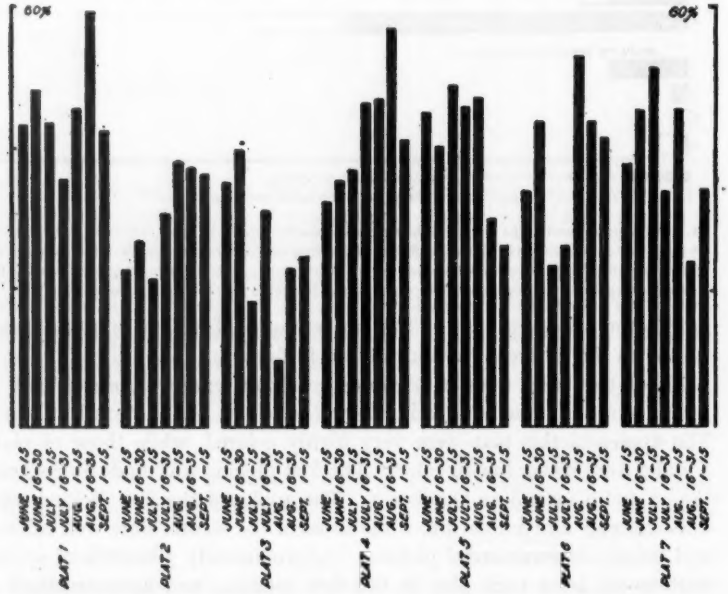

FIG. 9.—Diagram showing the soil-moisture conditions on plats of Jonathan apples in 1916. The average percentage of saturation is given for each half month and is based on soil samples taken at a depth of 16 inches. Plat 1 received heavy irrigation throughout the season; plat 2, medium; plat 3, light; plat 4, medium followed by heavy; plat 5, heavy followed by light; plat 6, heavy in June, medium in July, and heavy in August and September; plat 7, heavy till the middle of July, medium till August, heavy the first half of August, and medium the remainder of the season.

The relative susceptibility to bitter-pit of the apples from the different plats was the same as in previous experiments, the fruit from the trees receiving heavy irrigation late in the season having the largest amount of disease, that from those heavily irrigated throughout the season the next, and that from those receiving heavy irrigation followed by light having the least (fig. 10). As was found in the experiments of 1915, the apples from the early picking showed much greater susceptibility to bitter-pit than those of the late picking.

The size of the apples from the various plats and the relative susceptibility of the different sizes to bitter-pit is shown in Table IX.

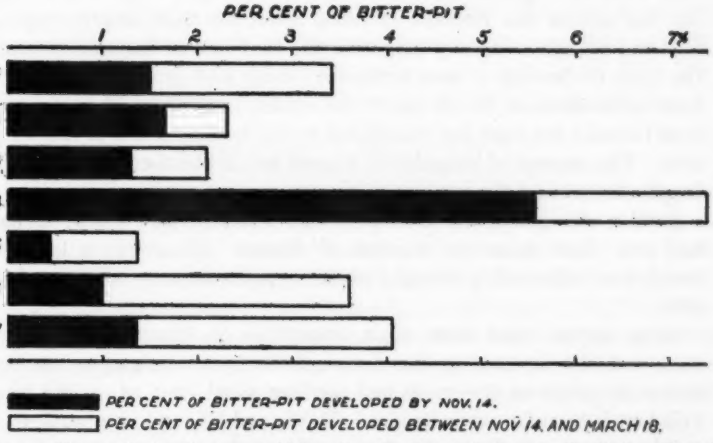

FIG. 10.—Diagram showing the amount of bitter-pit on Jonathan apples in 1916. The black portions of the bars indicate the percentage of apples affected with bitter-pit on November 14 and the white portions the percentage developed between November 14 and March 18. See figure 9 for soil-moisture conditions.

TABLE IX.—*Percentage, according to size, of Jonathan apples affected with bitter-pit. March 18, 1916*

Plat.	Total number of apples.	Percentage of apples of various sizes.					Percentage of apples of various sizes affected with bitter-pit.					Total percentage of bitter-pit.
		3½ to 3¾ inches.	3¼ to 3½ inches.	3 to 3¼ inches.	2¾ to 3 inches.	2¾ inches and smaller.	3½ to 3¾ inches.	3¼ to 3½ inches.	3 to 3¼ inches.	2¾ to 3 inches.	2¾ inches and smaller.	
1....	579	.....	5.7	30.9	59.2	4.2	.....	18.2	5.0	1.3	0.0	3.5
2....	593	.....	.8	22.5	65.9	10.8	.....	.0	3.8	2.2	1.5	2.3
3....	445	.....	.7	1.1	40.5	57.7	.....	.0	20.0	4.4	.4	2.2
4....	440	0.5	17.7	42.8	34.5	4.5	50.0	23.1	6.4	1.3	.0	7.5
5....	946	.....	1.3	16.3	68.4	14.0	.....	8.3	3.9	.9	.0	1.4
6....	566	.4	9.6	43.3	43.3	3.4	.0	20.0	2.9	1.2	.0	3.7
7....	542	.....	4.1	32.4	59.6	3.9	.....	9.1	6.3	3.1	.0	4.2

The plats receiving heavy irrigation late in the season had more large apples than the others. The amount of bitter-pit on the fruit of

a particular size was hardly sufficient to form a basis for conclusions, but it is evident that the disease was worse on the large apples than on the small, and that with the exception of one or two cases where there were but few apples heavy irrigation increased the amount of disease on the medium-sized as well as on the large fruit.

DISCUSSION OF RESULTS OF BITTER-PIT EXPERIMENTS

The results of the various experiments have been uniformly consistent in showing that heavy irrigation favors the development of bitter-pit. Heavy irrigation throughout the season has given less of the disease than medium irrigation followed by heavy, and light irrigation throughout the season has resulted in more bitter-pit than heavy irrigation followed by light. Heavy irrigation the first half of the season caused the trees to develop a more luxuriant foliage and probably produced a lower concentration of cell sap in the apples, both of which facts would tend to make the fruit less susceptible to the forcing effects of late irrigation. The amount of irrigation in August and September has apparently largely determined the amount of disease.

Sudden changes in the amount of soil water do not appear to have had any effect upon the amount of disease. No evidence has been found that bitter-pit is brought about by a rupture or bursting of the cells.

Large apples have been more susceptible to bitter-pit than small ones, but the increase in the disease from heavy irrigation has been almost as great on the small and medium sized fruit as on the large. This fact is brought out in Tables I, V, VI, and IX, and in a particularly striking manner in figure 6. Apparently apples are not susceptible to bitter-pit merely because they are large, but rather because of conditions that may sometimes accompany an increased growth.

The results as a whole point to the harmful effects of heavy late irrigation regardless of the size of the fruit. In looking for the final cause of the disease not only the direct growth-forcing effects of the water should be considered but also the effects of the excess water upon the soil flora and soil solutes. This subject will be more fully discussed in a later publication upon the effects of fertilizers.

JONATHAN-SPOT

HISTORICAL REVIEW

Jonathan-spot was first reported by Scott (*17*). He suggested the possibility that the trouble might be due to the effects of arsenate of lead. Later Scott and Roberts (*18*) gave a fuller report on the disease, showing that it could not be due to the effects of spraying and that while fungi were sometimes present in the spots they could not be taken

as the causal agency. They considered the disease of a physiological nature and found that it could be partially prevented by early picking, prompt cold storage, and early consumption after removal from storage.

Norton (*15*) reported that spots practically identical in appearance with the Jonathan-spot could be produced by the gases of ammonia and folmaldehyde.

Cook and Martin (*3*) considered Jonathan-spot to be a form of rot caused by a species of Alternaria. In a later report (*4*) they made a distinction between the small, nearly black, typical Jonathan-spots that were more commonly confined to the dark area of the skin, and the larger light-brown "Alternaria" spots that were more common on the lightest area of the skin. They reported that they were able to reduce the amount of the disease by keeping the apples covered with glassine bags during the latter part of the summer, and considered that this fact furnished further evidence that the spots were of fungus origin.

DESCRIPTION OF JONATHAN-SPOT

"Jonathan-spot" is the term applied to superficial black or brown spots that are especially common on Jonathan apples. The trouble is also found on Esopus, Yellow Newtown, Stayman Winesap, and other varieties. In the early stages of the disease only the surface color-bearing cells are involved and the spots are seldom more than 2 mm. in diameter, but later the spots may enlarge to a diameter of 3 to 5 mm., become slightly sunken and spread down into the tissue of the apple to a considerable depth. In this later stage of the disease rot fungi are often present, Alternaria being particularly common.

EXPERIMENTAL WORK

The Jonathan-spot experiments were carried out in the same Jonathan orchard and on the same apples as the bitter-pit experiments, and the details in regard to soil, irrigation, time of picking, and condition of storage have already been given.

In 1915, plat 5 suffered severely from drouth the latter part of the season, the trees finally losing more than three-fourths of their foliage and the fruit becoming badly bronzed by the sun. Plats 2 and 3 also became very dry in August but there was no defoliation. The soil moisture conditions for the season are given in figure 7. The first picking was made September 3. The fruit at this time lacked fully 10 days of being at its best stage of maturity for picking. A second picking was made on September 17 and a third picking on October 1. The fruit of the last picking was highly colored and dead ripe.

There was no Jonathan-spot at picking time. The results of notes taken on November 10 and February 1 are given in Table X.

TABLE X.—*Percentage of Jonathan apples affected with Jonathan-spot in 1915*

Date of picking.	Plat No.	Total number of apples.	Percentage of apples of following sizes.		Percentage of apples affected with Jonathan-spot.					
					November 10.			February 1.		
			Larger than 2½ inches.	2½ inches and smaller.	Apples larger than 2½ inches.	Apples 2½ inches and smaller.	Total.	Apples larger than 2½ inches.	Apples 2½ inches and smaller.	Total.
Sept. 3	1	281	84	16	24	11	22	52	50	51
	2	237	86	34	18	0	15	45	32	41
	3	338	62	38	5	3	4	54	72	62
	4	250	93	7	13	6	12	38	28	38
	5	179	49	51	2	3	3	22	18	20
Sept. 17	1	260	98	2	34	0	33	67	17	65
	2	291	81	19	18	4	15	48	45	47
	3	354	79	21	23	16	21	77	65	76
	4	195	94	6	17	8	16	93	67	92
	5	56	52	48	3	0	2	38	15	27
Oct. 1	1	183	95	5	17	22	18	79	33	77
	2	198	78	22	3	1	2	72	30	63
	3	267	60	40	11	4	8	79	35	61
	4	173	92	8	4	0	2	62	79	64
	5	.....	.....	.....	.....	.....	.....	.....	.....	.....
Total for all pickings	1	724	92	8	26	12	25	64	47	62
	2	726	82	18	14	2	12	52	37	49
	3	959	67	33	14	6	11	71	58	67
	4	618	93	7	12	5	11	62	54	62
	5	235	50	50	3	3	3	26	18	22

There was more Jonathan-spot on the large apples than on the small ones, and at the time of the first note-taking there was more on the fruit of the first and second pickings than on that of the third. Irrigation apparently had but little effect upon the disease. The apples from plat 5 had the least Jonathan-spot; but, as already mentioned, these were badly sunburned and therefore not suitable for use in comparison with those of the other plats.

In 1916 the experiments were continued in the same orchard. All the trees were in a healthy, vigorous condition except those of plat 3. These were the same as used in plat 5 the preceding season and showed the effects of the previous year's drouth in their thin foliage and short twig growth. The soil-moisture conditions for the various plats are given in figure 9. Pickings were made on September 22 and October 2. The fruit from plats 5 and 7 was rather poorly colored, while that from plat 3 was very highly colored. The conditions of storage have already been given in connection with the notes on bitter-pit. The results for the season are shown in Tables XI and XII.

TABLE XI.—*Percentage of Jonathan apples affected with Jonathan-spot in 1916*

Plat No.	Irrigation treatment.	Percentage of apples affected with Jonathan-spot.					
		November 14.			March 18.		
		First picking.	Second picking.	Total.	First picking.	Second picking.	Total for year.
1	Heavy	1.3	0.3	0.8	55.8	82.8	65.4
2	Medium	3.8	0.0	2.1	51.2	57.3	54.2
3	Light	13.5	0.0	11.8	72.2	31.1	66.5
4	Medium, followed by heavy	7.9	.6	3.0	66.3	73.2	69.1
5	Heavy, followed by light	.5	0.0	.3	18.2	37.7	24.0
6	Alternating, heavy, medium, heavy	3.4	.4	2.1	53.3	77.4	64.7
7	Alternating, heavy, medium, heavy, medium	.3	.6	.4	16.2	33.9	23.8

TABLE XII.—*Percentage, according to size, of Jonathan apples affected with Jonathan-spot in 1916*

Plat No.	Total number of apples.	Percentage of apples of various sizes.					Percentage of apples of various sizes affected with Jonathan-spot.					
		3¼ to 3½ inches.	3¼ to 3¼ inches.	3 to 3¼ inches.	2¾ to 3 inches.	2¾ inches and smaller.	3¼ to 3½ inches.	3¼ to 3¼ inches.	3 to 3¼ inches.	2¾ to 3 inches.	2¾ inches and smaller.	Total.
1	579	.....	5.7	30.9	59.2	4.2	.....	72.8	61.5	66.8	66.6	65.4
2	593	.....	.8	22.5	65.9	10.8	.....	60.0	53.4	52.9	62.5	54.2
3	445	.....	.7	1.1	40.5	57.7	.....	.....	60.0	58.3	73.2	66.5
4	440	0.5	17.7	42.8	34.5	4.5	.....	55.0	68.7	77.7	70.0	69.1
5	946	.....	1.3	16.3	68.4	14.0	.....	33.3	18.8	24.7	26.6	24.0
6	566	.4	9.6	43.3	43.3	3.4	100.0	38.2	65.3	69.8	63.2	64.7
7	542	.....	4.1	32.4	59.6	3.9	.....	13.6	22.7	25.1	23.4	23.8

On November 14 the Jonathan-spot was worse on the apples of the first picking than on those of the second, but by March 18 this condition had in most cases been reversed. There was little contrast between the amount of disease on the fruit of different sizes. The contrasts between the irrigation plats were not very consistent, but in general indicated that heavy irrigation favored the disease. Plats 5 and 7, on which the fruit was lowest in color, had least of the disease.

DISCUSSION OF RESULTS ON JONATHAN-SPOT

The experiments on Jonathan-spot have furnished little in the way of consistent positive results. In both 1915 and 1916 the apples of the early picking had more of the disease than those of the late picking. In 1915 the large apples developed more Jonathan-spot than the small ones, but this did not hold in 1916. The results of both years gave some evidence that heavy irrigation was more favorable to the disease than light irrigation, but there was nothing to indicate that the amount of soil moisture was an important factor in determining the amount of Jonathan-spot.

OTHER PHYSIOLOGICAL SPOT DISEASES OF THE APPLE

DROUTHSPOT

The term "drouthspot" (*2*) has been applied to certain fairly large areas of dead brown tissue usually occurring near the surface of the apple, but sometimes found deeper in the flesh. The disease may appear at almost any stage in the development of the apple, but the fruit appears to be more susceptible after it is one-third grown. The spots are usually located on the blossom half of the fruit. In typical cases the trouble first appears as large, irregular, water-soaked spots that often have a reddish margin and are usually covered with drops of a yellowish, sticky ooze that is sweetish to the taste, and later hardens into a brittle, crystalline-like deposit (Pl. 3, D). At this stage the spots resemble fireblight infection (caused by *Bacillus amylovorus*) and are sometimes mistaken for it. Upon cutting the apple open a very shallow layer of dead brown tissue is found in the region of the vascular network just beneath the skin. Occasionally brown streaks follow the vascular bundles deeper into the apple pulp. The affected tissue is very bitter to the taste. The skin of the apple over the diseased area finally regains its normal appearance; but growth is arrested at this point, and the enlargement of the surrounding tissue soon gives rise to a much misshapen apple (Pl. 3, E, F). On account of its manner of development, the disease has sometimes been referred to as "spot-necrosis" (*13*). Mix (*14*) has given a full discussion of the characters of the disease as it occurred in the Champlain Valley of New York.

The above description applies particularly to the trouble as it has been observed on Winesap and Stayman Winesap apples in the irrigated sections of the West. It was first produced experimentally at Wenatchee, Wash., in 1913, by subjecting Winesap trees to a sudden and severe drouth when the fruit was about 1 inch in diameter. At about the same time it was observed at Peshastin, Wash., on Ben Davis trees that had suffered from a similar drouth. It occurred again at Wenatchee in 1914 and in 1915, always on trees that had been subjected to a sudden and severe drouth and that had been making a normal or vigorous growth earlier in the season. The drouth periods resulted from trouble with the irrigation canals. The affected trees were usually located on shallow soils or on soils underlain with coarse gravel at a slight depth, thus making them peculiarly susceptible to drouth.

In 1915 a series of drouth periods occurred, the first and most severe coming the latter part of June and the first of July, the second the latter part of July, and the third about the middle of August. At the time of the first drouth even the trees on deep soil began to suffer, and those on shallow soil lost a large percentage of both their foliage and fruit. The fruit that remained on the trees was much shrunken in size, sometimes being reduced to two-thirds its normal diameter. White Pearmain ap-

ples became very badly shriveled and wrinkled (Pl. 5, C), and Jonathan and Delicious apples showed slightly less serious effects; but with the return of irrigation water all of these regained their turgor without spotting. The Winesap and Stayman Winesap apples did not become as badly shriveled as the White Pearmain, but they developed typical drouthspots before they became shriveled. It was also observed that the oozing of the fruit sap, as well as the spotting of the fruit, preceded the renewal of irrigation. The apples subjected to the early drouth were also involved in the later ones, and the result was a series of spots on the same apples that could be distinguished as to time of formation by the color of the skin and the depth of the pitting.

On September 3 samples of fruit were obtained from the Jonathan trees that had suffered most severely from drouth, and on October 13 similar samples were secured from the Winesap, Stayman Winesap, and White Pearmain trees. All of the apples were placed in cellar storage until January 13 and were then cut open and examined. The Jonathan and White Pearmain apples had developed no spots, but their flavor was decidedly poor. With the Winesap and Stayman Winesap apples the spots had not enlarged, and there was but little brown tissue beneath the skin (Pl. 3, F). The flavor of the affected tissue was bitter and acrid, but that of the rest of the apple was normal.

The above trees that had suffered from drouth appeared to recover largely before the close of the season and their leaves came out normally the following spring; but a number of them died a few months later, and the remainder showed a lack of vigor throughout the summer. Their foliage was thin and they appeared to suffer from drouth even with a slight decrease in the percentage of soil moisture. The usual number of irrigations were made, and there were no real drouth periods; yet more than half of the apples on some of the Winesap and Stayman Winesap trees developed typical drouthspots. The weak condition of these trees and the death of others earlier in the summer probably resulted from the destruction of some of the smaller roots during the drouth of the preceding season.

CORK

The disease or group of diseases called "cork" may be similar to drouthspot in cause, but is distinctly different in many of its gross characteristics. Instead of being subepidermal, the spots are located in the pulp of the apple, often quite deeply seated and often closely associated with the larger vascular bundles (Pl. 5, B). The patches of dead, brown tissue are usually much larger than in the case of bitter-pit and much deeper than in drouthspot. They resemble the internal browning of the former disease, but are firmer in texture, more corky, and less spongy. Affected apples are often slightly less firm than others, and usually have a cheesy consistency when cut. When the spotting occurs near the core

only, there is usually no external marking to indicate the disease; but when the outer pulp tissue is affected, depressions occur over the dead spot, and the apple becomes more or less roughened or corrugated (Pl. 5, A, B). The development of the disease in the case of these corrugated apples is similar to that of drouthspot in many respects. It appears first as reddish stains on the surface of the apples, and these stained areas may gradually become water-soaked and covered with a sticky yellow ooze. Later the skin regains its normal color, but large areas of dead, brown tissue are left in the pulp.

Apples affected with cork are sometimes also affected with a condition known locally as "apple-blister." The trouble first appears as slightly raised brown or reddish spots on the skin of the apples (Pl. 5, E). The center of the raised portions is very hard and corky, but only the outer epidermal layers are involved. As the apple develops, the blisters crack and scale off, exposing a rough corky layer that has formed beneath. The later stages of blister have usually been found on apples that were also affected with cork, but blister appears early in the spring, very often becoming evident as soon as the petals have fallen.

Troubles identical with cork, or very similar to it, are quite widely distributed. They have been observed by the writers in the Wenatchee, Entiat, Spokane, Okanogan, and White Salmon districts of Washington, in the Willamette and Hood River Valleys of Oregon, in the Okanogan district of British Columbia, in the Champlain Valley of New York, and in various apple sections of Virginia and West Virginia. It is evident from McAlpine's reports (*9–12*) that the disease is of considerable importance in Australia.

McAlpine's (*9–12*) photographs indicate that he included the disease under the name "bitter-pit." Lewis (*8*) included "corerot" and "dryrot" as forms of fruitpit or bitter-pit. Allen (*1*) referred to the disease as "fruitpit." Mix (*14*) has very carefully distinguished between cork and bitter-pit. In British Columbia the disease is known as "malformation" and in Washington as "dryrot." A trouble known in Virginia as "York-spot," or "punky disease" (*16*), and in California as "hollow-apple" are apparently very closely related to cork.

The losses from the disease are usually local, but sometimes severe. At Entiat, Wash., in 1916, two carloads of apples from one 20-acre orchard were rendered worthless on account of cork. On the lower flats of the Okanogan Valley in British Columbia it is regarded as the most serious of all apple troubles, and in certain sections of the Hood River Valley, Oreg., it was the cause of considerable annual loss prior to the introduction of systematic irrigation.

The cause of cork is not known. Allen (*1*) has reported that fruitpit is worse on trees in a dry soil or in a soil lacking in organic matter. The disease is apparently not produced by fungi or insects. The writers have made repeated attempts to isolate an organism from the

affected tissue, but with negative results. Close observations have been made on the work of insects in orchards where the disease was serious, but no evidence has been secured to indicate the association of any insect with the production of the disease. Orchards affected with rosette are sometimes also affected with cork, but the latter disease occurs in orchards that are free from the former. In nearly every case where the disease has been observed either in the East or West, its occurrence in the orchard has been closely correlated with certain peculiar soil conditions; sometimes an excess of alkali or an outcropping of slate, but more often a shallowness or openness of the soil. In most sections cork has been most serious when there was a shortage in soil-water supply, either resulting from light rainfall or a lack of irrigation.

An orchard at Entiat, Wash., that has been seriously affected with cork has been under close observation for the past three years. The orchard is located on a low bench near the Columbia River, and has had a permanent cover crop of alfalfa. Soil samples from the orchard showed that in the sections where spotting had been most prevalent the surface soil was only about 3 inches deep and was composed of a coarse sand with only a small percentage of humus. The subsoil, which was more than 6 feet deep, differed from the surface soil only in the absence of the humus and was underlain with coarse gravel. In sections of the orchard where spotting had been less prevalent, the soil was found to be a much finer sand, and in sections where no spotting had occurred it was a typical volcanic ash, very fine in texture, closely compacted when wet, and very retentive of moisture. Soil-moisture determinations made soon after the spring rains showed that while the surface soils in the different orchard sections retained their moisture fairly well, the subsoil in the first section dried out quickly and that in the last section was very retentive of its moisture. It will be seen that the occurrence of the disease varied with the character of the soil, particularly with the water-holding capacity of the subsoil.

The irrigation of the orchard was inadequate. The furrows were 5 feet from the tree rows, and alfalfa growing near the trees and in the tree rows was yellow, frequently wilted, and very evidently suffering from lack of water. The trees suffered from drouth, especially in the spring, before the irrigations were begun. In 1916 the first irrigation was made several weeks later than usual and the trees became very dry. Later the apples developed an unusually high percentage of cork, the disease first appearing in blister form soon after the petals had fallen. The conditions in the orchard indicated that the soil-water supply was at least one important factor in determining the amount of disease.

The circumstances under which cork and drouthspot have occurred in the Champlain Valley have been quite fully described by Mix (*14*).

A special form of cork known in certain sections as "Yorkspot" and in others as "hollow-apple" has been found particularly common on

York Imperial apples and has also occurred on the Gano and the Esopus varieties. The disease has been under close observation for several years at Wenatchee, Wash., and in the summer of 1916 a careful study was made of it in orchards at Staunton, Va. In the latter case the disease was found only on York Imperial apples. It could not be correlated with any peculiar soil conditions, but was found decidedly worse on trees that were lightly loaded than on those with a medium or heavy crop. It was much worse on the south side of the tree than on the north side and slightly worse on the east side than on the west. It occurred almost exclusively on apples well exposed to sunlight, always on the blush side of the fruit, and always on fruit surfaces that would receive the oblique rather than the direct rays of light. The spots were similar in appearance to cork, but, instead of being scattered over the apple, were often located in a crescent-shaped line at the edge of the blush surface of the fruit. In some cases there was a definite ring almost entirely surrounding the point which received the most direct sunlight (Pl. 5, F, G). The skin of the apple was always normal, and the corky tissue beneath was usually indicated by surface depressions. While it seems probable that Yorkspot is in part an effect of drouth, its occurrence is undoubtedly greatly influenced by sunlight and possibly by soil conditions and other agencies.

The observations reported above seem to indicate that cork is a form of drouth injury; yet the disease appears to differ from typical drouthspot, both in characteristics and conditions of occurrences. With certain varieties of apples drouthspot can apparently be produced on any soil under conditions of sudden and extreme drouth. Cork seems to be the result of a less severe but more chronic drouth on trees located on certain peculiar soils, especially on soils that are lacking in humus and are not retentive of moisture. Blister is closely associated with cork and is probably produced by the same agencies.

It should be noted in this connection that the harmful effects of drouth are not always in proportion to the degree of desiccation. Other factors must be considered in a study of drouth troubles, and among these are the percentage of harmful substances in the soil water and the general growth condition of the plant.

SUMMARY

(1) Bitter-pit and Jonathan-spot are distinguished from rosy-aphis stigmonose, drouthspot, cork, and blister. Bitter-pit usually appears first as spots of dead, brown tissue in the subepidermal portion of the apple. These spots are associated with the terminal branches of the vascular bundles and in later stages of the disease the browning often follows the vasculars deep into the flesh of the apple. Rosy-aphis stigmonose is characterized by similar brown spots in the subepidermal region

but the affected tissue is firmer than in the case of bitter-pit and there is no association with the vascular bundles. The early stages of Jonathan-spot are confined to the color-bearing cells of the skin of the apple. Drouthspot is characterized by the checking of the growth at certain points on the apple without the production of any large quantity of corky tissue. Cork differs from the drouthspot in the presence of comparatively large spots of brown corky tissue and in the fact that these are usually rather deeply seated in the flesh of the apple. Blister is a superficial lesion associated with cork and characterized by its blister-like appearance.

(2) Drouthspot has been produced by sudden and extreme drouth. It has occurred on trees that were favorably located as well as on those that were growing under rather unfavorable soil conditions. Cork is apparently also a drouth effect, but it differs from drouthspot in the fact that its occurrence is usually associated with certain peculiar soil types.

(3) Experiments have shown that there is a close relationship between the soil-water supply of the orchard and the development of bitter-pit in storage. Heavy irrigation has greatly increased the disease, but not so much as medium irrigation followed by heavy irrigation. Light irrigation has greatly reduced it, but heavy irrigation followed by light has resulted in the lowest percentage of the disease. Sudden changes in the amount of soil water have apparently not increased the disease.

(4) Heavy irrigation may have been slightly favorable to the development of Jonathan-spot, but the contrasts have been too slight to justify definite conclusions.

(5) Large apples have shown greater susceptibility to bitter-pit than small ones, but with Jonathan apples heavy irrigation increased the disease on the medium-sized fruit as well as on the large, and with Grimes the percentage of increase from heavy irrigation has been even greater on small apples than on large ones. Apparently, large apples are not susceptible to bitter-pit merely because they are large, but rather because of certain conditions under which they become large.

(6) In 1915 there was more Jonathan-spot on the large apples than on the small ones, but in 1916 there seemed to be no correlation between size of fruit and severity of disease.

(7) During the first weeks of cellar storage there was always more Jonathan-spot developed on apples that were picked early than on apples that were picked late, but with longer periods of storage these contrasts seemed to largely disappear. The results indicate, however, a greater susceptibility in the early-picked fruit.

(8) Bitter-pit was worse on the Jonathan appies that were picked early than on those that were picked late.

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PLATE 2

A.—Early stage of bitter-pit on Northern Spy apple from Westminister, Vt., November 16, 1916.

B.—Cross section of the apple shown in A. Brown spots are evident just beneath the skin, and a few others can be seen deeper in the flesh of the apple.

A

B

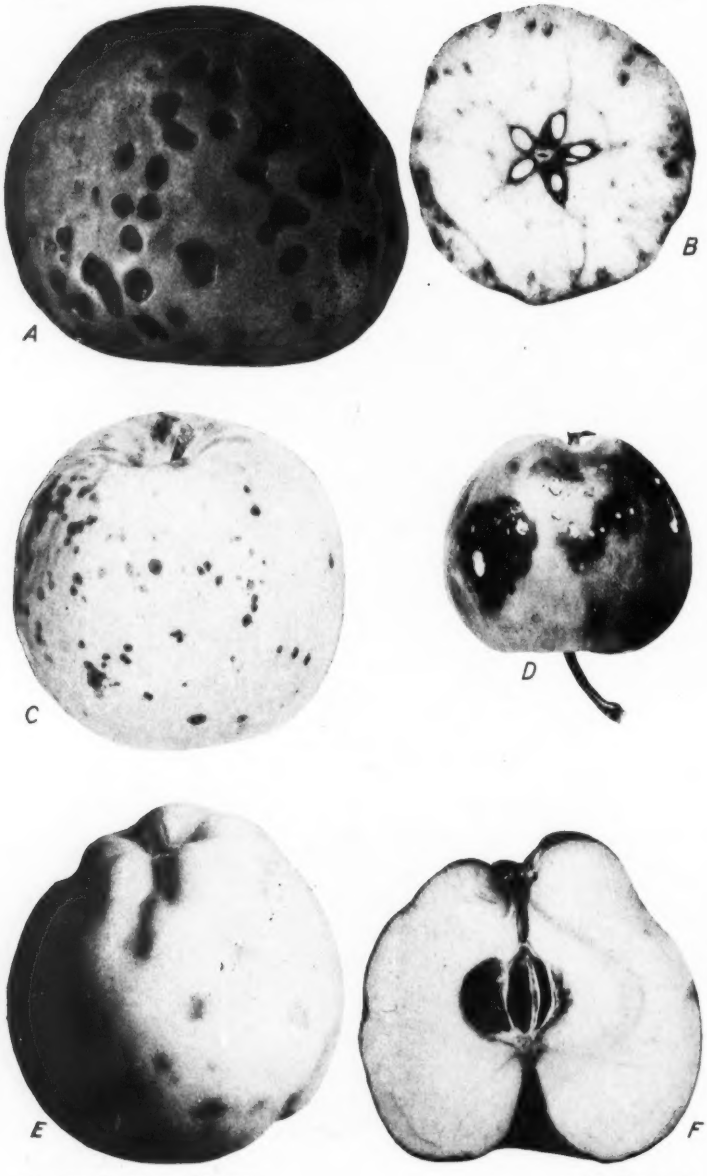
A
B
C
D
E
F

PLATE 3

A.—Late stage of bitter-pit on Rhode Island Greening apple.

B.—Internal browning accompanying bitter-pit.

C.—Jonathan-spot on Jonathan apple.

D.—Early stage of drouthspots on a Winesap apple from Wenatchee, Wash. The drops of exudate can be seen on the surface of the apple.

E.—Late stage of drouthspots on a Winesap apple. Note the deep depressions scattered over the surface of the apple.

F.—Cross section of the apple shown in E. Note the almost entire absence of brown corky tissue.

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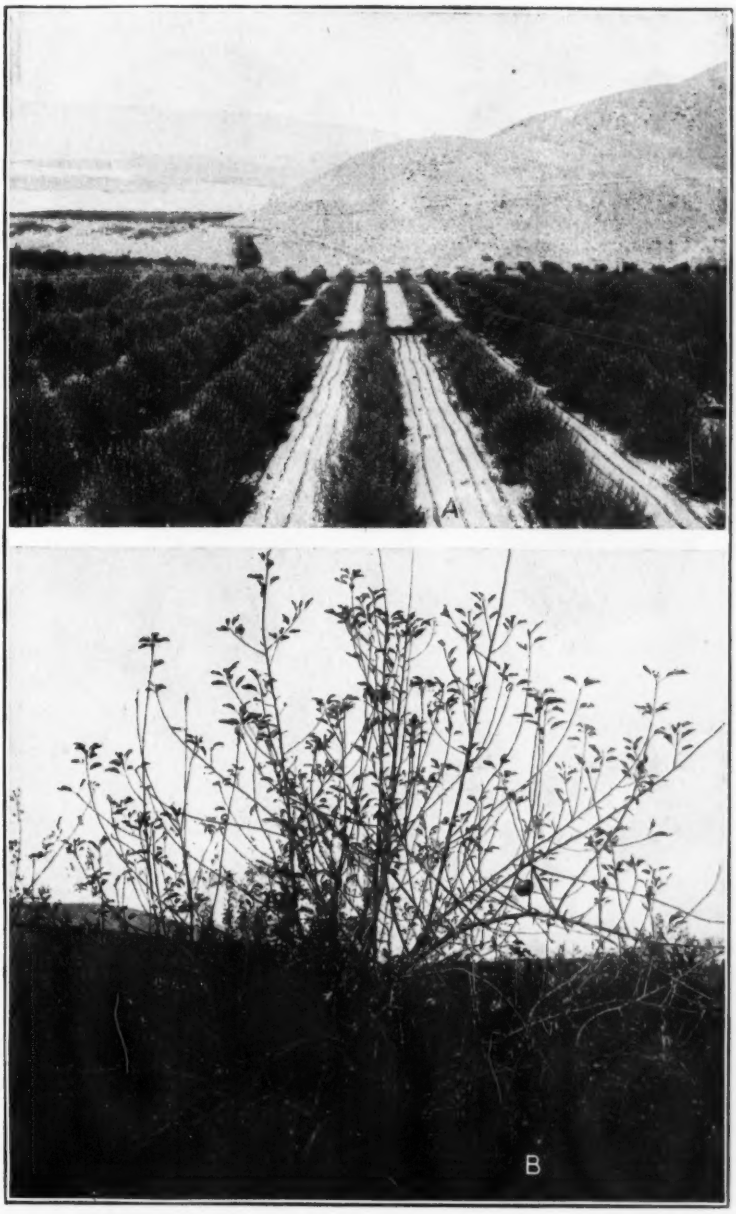
PLATE 4

A.—An apple orchard showing the furrow system of irrigation employed in the experimental work at Wenatchee, Wash.

B.—Jonathan apple tree showing the effects of drouth, Wenatchee, Wash. Photographed on September 1, 1915.


A
B

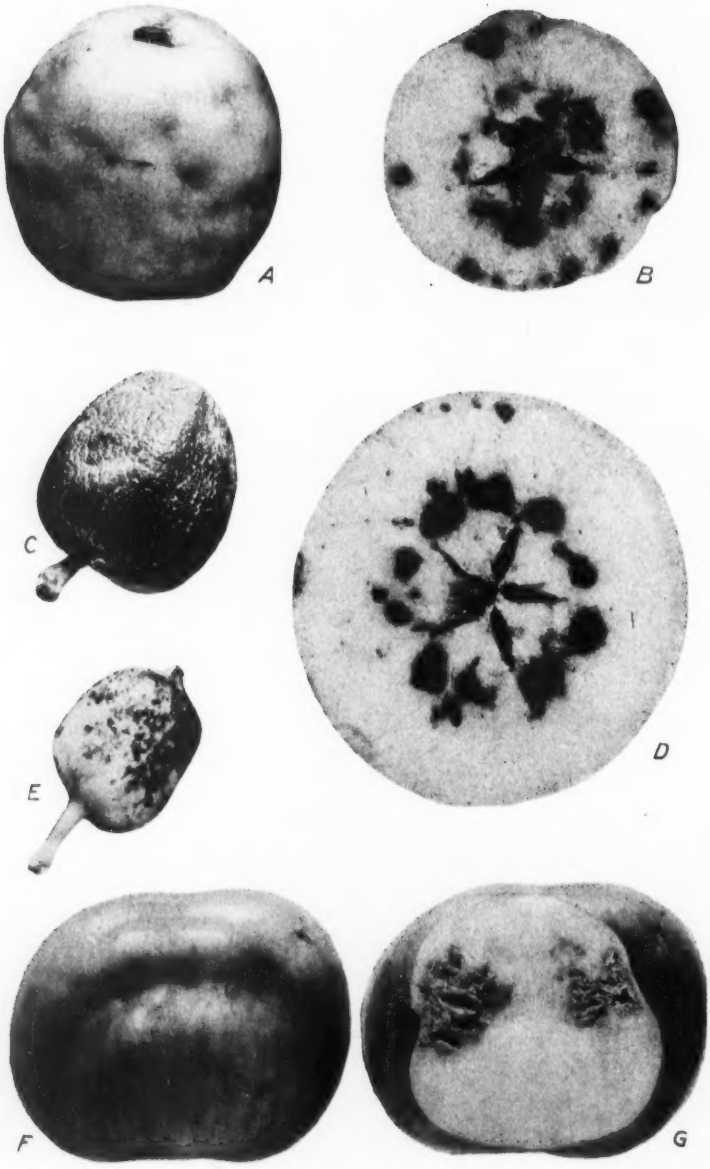

A
B
C
D
E
F
G

PLATE 5

A.—Cork on Yellow Newtown apple from Hood River, Oreg. Note the roughene, appearance.

B.—Cross section of the apple shown in A. Note the area of brown corky tissue.

C.—White Pearmain apple showing the severity of the 1915 drouth at Wenatchee, Wash. No drouthspots were developed on such apples.

D.—Cork, or "dryrot", on a King apple. Note the brown corky tissue near the core. In surface view such an apple appears normal.

E.—Blister on an Esopus apple from Entiat, Wash.

F.—An extreme case of Yorkspot on a York Imperial apple. Note the circular nature of the injury.

G.—Cross section of the apple shown in F. Note the pockets and the brown corky tissue beneath the surface depression.

RELATION OF CARBON DIOXID TO SOIL REACTION AS MEASURED BY THE HYDROGEN ELECTRODE[1]

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INTRODUCTION

In a previous article (*11*)[2] the authors have presented data concerning the question of soil reaction as determined by the hydrogen electrode. Since this work did not include direct measurements of the effect of carbon dioxid on the reaction of soils, it was thought desirable to carry out further experiments on this point. Before discussing the data obtained in these additional experiments it will be well to emphasize again the fundamental principles upon which the conclusions of our first paper were based.

The present tendency to advance involved explanations of the nature of soil acidity seems to be unnecessary, for the simple conception of the relations of H- and OH-ion concentrations are in accord with the facts so far ascertained and are warranted by the accepted teachings of chemistry. The lack of agreement in the literature appears to be due to the attempt to use interchangeably the terms "lime requirement" and "soil acidity." In the methods of determining the lime requirement it is proposed to measure the amount of lime required to bring the soil to an end point dependent upon arbitrarily selected conditions. These methods are in themselves so varied and the final measurement of reaction so difficult, that the discordant results which appear in the literature are wholly to be expected.

On the other hand, the term "soil acidity" has a definite and precise meaning—namely, that condition of the soil in which its aqueous solution contains H ions in excess of OH ions. In our opinion it would be preferable to refer to soil acidity, soil neutrality, and soil alkalinity as those phases of soil reaction in which the H-ion concentration is respectively greater than, equal to, or less than the OH-ion concentration. These H- ion concentrations may be definitely determined by measurements with the hydrogen electrode.

The lime requirement, in so far as it is related to soil acidity, would consist of that amount of lime necessary to bring an acid soil to the neutral point as ascertained by the above-mentioned procedure. Such a lime requirement implies that the dissolved and total undissolved soil acids have been neutralized. To put this procedure into practice may involve

[1] From the Divisions of Agricultural Chemistry and Soil Chemistry and Bacteriology in equal cooperation.

[2] Reference is made by number (italic) to "Literature cited," p. 147–148.

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certain inherent difficulties. The reaction is so prolonged either by the slow rate of solution of the soil acids or their slow diffusion through the soil particles that the point of neutrality may not be easy to establish and maintain permanently. Thus an apparent state of equilibrium at the neutral point may be attained with a subsequent slow return to an acid condition, owing to the solution and diffusion of the soil acids. But once the total soil acids have been neutralized, a further return to an acid condition can come about only through leaching processes or, possibly, in a few cases through decomposition of organic matter.

As pointed out, some soils whose solutions are neutral or alkaline remove considerable quantities of calcium hydroxid from the solution without materially increasing the OH-ion concentration of the soil suspension. In certain cases this reaction might be erroneously attributed to the soil acids. Although the term "lime requirement" is in common usage in agricultural literature, it has been variously interpreted by different investigators. At present the term is devoid of scientific significance. In distinction thereto soil reaction whether acid, neutral, or alkaline, is capable of precise definition and determination.

EFFECT OF CARBON DIOXID ON SOIL REACTION

In considering the effect of carbon dioxid on soil reaction MacIntire (*8*) states that many acid soils when extracted with water saturated with carbon dioxid yield alkaline extracts. He also makes the following conclusion:

> Since we admit that the soil solution is the medium through which a plant absorbs its mineral supply, we are compelled to conclude that a plant's source of nutrition is almost always alkaline, but of varying degrees of alkalinity.

From the nature of the chemical equilibria involved (*2*, *9*, *4*), we have been unable to reach the conclusion that a solution existing in contact with an acid soil can ever become alkaline owing to any change in the partial pressure of carbon dioxid. An increase in carbon-dioxid tension would either be without effect upon the H-ion concentration, or else would increase it, depending upon the relative dissociation constants of carbonic acid and the soil acids. It is conceivable that certain acid soils when extracted with water saturated with carbon dioxid might yield filtrates which would give an alkaline reaction after their carbon-dioxid content had come into equilibrium with the partial pressure of atmospheric carbon dioxid, but the equilibria governing the reaction of the soil solution in contact with the soil are by no means identical with those regulating the reaction of the filtrate obtained from such a soil.

In order to obtain direct evidence on the influence of carbon dioxid on soil reaction, the experiments reported in this paper were undertaken. The method of procedure was similar to that previously described by the authors, with the addition of an arrangement for controlling the partial pressure of carbon dioxid in the atmosphere above the soil. By adopting

a simplified form of the apparatus used by McClendon and Magoon (7) and McClendon (6) for investigating the H-ion concentration of sea water, we have been able to obtain the desired data.

DESCRIPTION OF APPARATUS AND RESULTS OBTAINED

The hydrogen-electrode apparatus was the same as that previously described in this journal. To provide a chamber for mixing the hydrogen and carbon dioxid a graduated 1,000-c. c. cylinder, the base of which had been cut off, was immersed in a larger cylinder filled with mercury. The upper end of the inner cylinder was tightly stoppered and contained two capillary stopcocks for admission and outlet of the gases. A definite quantity of purified hydrogen, electrolytically generated, was admitted to this cylinder through one stopcock. Through the other stopcock there was admitted from a gas burette a known quantity of pure carbon dioxid. Both gases were measured at atmospheric pressure. A sufficient time was then allowed for the thorough diffusion of the gases, which was aided by raising and lowering the inner cylinder. The reservoir of mixed gases was then connected to the hydrogen-electrode chamber which contained the soil suspension. Forty to seventy c. c. of the gas mixture were forced into the space above the soil suspension, adjusted to atmospheric pressure, and the hydrogen-electrode cell was then closed. Equilibrium was hastened by the shaking method, and the voltmeter readings were noted. This procedure was repeated with new portions of the gas mixture until the voltmeter readings were constant to within 0.005 volt. The experimental details and results are recorded in Table I.

The term "With previous carbonation" signifies that carbon dioxid has been passed through the soil suspension for a period of ½ to 2 hours previous to the determination of the H-ion concentration. The purpose of this step was to ascertain the effect of thoroughly saturating the soil with carbon dioxid upon its subsequent reaction. This also proved to be necessary in the case of some of the alkaline soils to insure complete saturation of the carbonates present, thus making it possible to attain the final equilibrium when using the smaller percentages of carbon dioxid, without the preparation of excessive quantities of the gas mixture. By satisfying in this manner the capacity of the soil to combine with carbon dioxid, it is possible to reach a partial pressure of carbon dioxid above the suspension in the hydrogen-electrode cell comparable to that in the mixing cylinder.

As expressed in Table I the 0 per cent of carbon dioxid means that several portions of pure hydrogen were used to obtain equilibrium. With such a technic the loss of carbon dioxid from the soil is minimized. Thus, the atmosphere above the suspension will undoubtedly contain a small percentage of carbon dioxid.

TABLE I.—*Effect of carbon dioxid on the reaction of soil suspensions*

Soil No.	Description of soils.	Quantity of soil.	Quantity of water.	Percentage of carbon dioxid in gas mixture by volume.	Reaction without previous carbonation.		Reaction with previous carbonation.	
					Readings on voltmeter.[a]	H-ion concentration.	Readings on voltmeter.[a]	H-ion concentration.
		Gm.	*C. c.*			*Gram-molecules per liter.*		*Gram-molecules per liter.*
1	Fine sandy loam (California)	10	50	0.00	0.589	0.40×10^{-4}	0.592	0.37×10^{-4}
1	do			.42	.590	$.40\times10^{-4}$		
1	do			1.90			.589	$.40\times10^{-4}$
1	do			9.00	.580	$.59\times10^{-4}$		
2	Silty clay loam (California)	10	50	.00	.783	$.17\times10^{-7}$	.763	$.38\times10^{-7}$
2	do			.22			.742	$.92\times10^{-7}$
2	do			.42	.747	$.73\times10^{-7}$		
2	do			.49			.744	$.85\times10^{-7}$
2	do			1.90	.726	$.18\times10^{-6}$	.726	$.18\times10^{-6}$
2	do			4.80	.709	$.34\times10^{-6}$		
2	do			9.00	.688	$.80\times10^{-6}$		
3	Clay loam (California)	10	50	.00	.896	$.20\times10^{-9}$		
3	do			.42			.773	$.26\times10^{-7}$
3	do			1.90			.768	$.33\times10^{-7}$
3	do			4.80	.753	$.59\times10^{-7}$		
3	do			9.00	.762	$.42\times10^{-7}$	.756	$.53\times10^{-7}$
4	Clay loam (Pennsylvania)	10	50	.00	.700	$.49\times10^{-6}$	.712	$.31\times10^{-6}$
4	do			.22	.687	$.84\times10^{-6}$		
4	do			1.90			.685	$.90\times10^{-6}$
4	do			9.00	.665	$.20\times10^{-5}$		
5	Clay loam (Louisiana)	10	50	.00	.667	$.18\times10^{-5}$	.665	$.20\times10^{-5}$
5	do			4.80	.644	$.46\times10^{-5}$	.647	$.40\times10^{-5}$
6	Silty clay loam (Wisconsin)	10	50	.00	.658	$.26\times10^{-5}$	.663	$.21\times10^{-5}$
6	do			1.90			.653	$.32\times10^{-5}$
7	Clay loam (Louisiana)	10	50	.00	.684	$.94\times10^{-6}$	.685	$.90\times10^{-6}$
7	do			1.90			.664	$.21\times10^{-5}$
8	Silty loam (California)	10	50	.00	.604	$.23\times10^{-4}$	.602	$.25\times10^{-4}$
8	do			1.90	.603	$.24\times10^{-4}$		
9	do	10	50	.00	.792	$.13\times10^{-7}$	.789	$.14\times10^{-7}$
9	do			.20			.770	$.30\times10^{-7}$
9	do			2.00			.726	$.18\times10^{-6}$
10	Silty clay loam (California)	10	50	.00	.770	$.30\times10^{-7}$		
10	do			.20			.764	$.38\times10^{-7}$
10	do			.42			.758	$.49\times10^{-7}$
10	do			1.90			.724	$.19\times10^{-6}$
10	do			4.90			.700	$.49\times10^{-6}$
11	do	10	50	.00	.782	$.19\times10^{-7}$		
11	do			.50			.755	$.55\times10^{-7}$
11	do			1.90			.735	$.12\times10^{-6}$
11	do			4.90			.718	$.24\times10^{-6}$

[a] Mercury cell, with mercuric chlorid and potassium chlorid in *N*/10 concentration.

Since the measurement of the H-ion concentration is based on hydrogen at atmospheric pressure, any diminution in this pressure caused by the admixture of carbon dioxid would result in a certain lowering of the electromotive force. Loomis and Acree (5) have determined the changes in electromotive force resulting from the diminution of the partial pressure of hydrogen within certain ranges. Their data indicate that these changes are so slight as to be without significance in the present investigation, hence no corrections for this factor have been made. Most of the determinations reported above are the averages of duplicates. The agreement of these duplicates was in nearly all cases within 0.005 volt.

The data in the above table have to do with the effect of carbon dioxid on three general types of soil reaction. The acid type of reaction is

represented by soils 1, 4, 5, 6, 7, and 8, the neutral or slightly alkaline type by soils 2, 9, 10, and 11, and the strongly alkaline reaction by soil 3.

Considering first the case of the acid soils, we note that the increase in H-ion concentration of the soil suspensions, in contact with even the higher percentages of carbon dioxid, is scarcely greater than the errors of observation. In soils 1 and 8, whose suspensions give H-ion concentrations of the magnitude 10^{-4}, there has been no perceptible change in reaction due to the presence of carbon dioxid. The other acid soils, which have a smaller concentration of H ion, show some slight increase in acidity when in contact with the mixture of gases containing carbon dioxid. This might be expected from a consideration of the relation of the dissociation of carbonic acid to that of the soil acids. Those soils whose acids dissociate comparably to carbonic acid are not measureably affected by the partial pressures of carbon dioxid used in these experiments, while soils containing less dissociated acids have their H-ion concentration increased to a slight extent by the carbon dioxid.

The H-ion concentration of suspensions of the slightly alkaline soils is appreciably increased by increasing the partial pressure of the carbon dioxid. The degree of increase in acidity seems to be dependent upon the proportion of carbon dioxid in the gas mixture. In fact, the higher percentages of carbon dioxid brought about a slightly acid reaction in the suspensions of these soils.

In case of soil 3, a so-called "alkali" soil, which had a very low H-ion concentration, a large increase was caused by the introduction of carbon dioxid into the hydrogen-electrode cell.

DISCUSSION OF RESULTS

The results recorded in this paper show that the effect of carbon dioxid on the H-ion concentration of soil suspensions is not an insurmountable difficulty in obtaining the reaction of soils under various conditions by means of the hydrogen electrode. The technic followed in the former investigation in which the loss of carbon dioxid is minimized, although not entirely avoided, evidently gives results of the same order of magnitude as would be obtained if there were no loss of carbon dioxid. The adoption of such a view is warranted by the fact that the maintenance of a small partial pressure of carbon dioxid above the soil suspension in the hydrogen-electrode cell, only altered the H-ion concentration by less than a magnitude. It should be remarked, however, that in soils containing alkali carbonates, and having a high OH-ion concentration, the partial pressure of the carbon dioxid exercises a very pronounced effect upon the reaction, as instanced by soil 3. For a clear exposition of equilibria governing such systems the reader is referred to Johnston (*4*).

So far we have not considered the question of H-ion concentration in soils under field conditions. By determining the carbon-dioxid content of the soil atmosphere under field conditions and then duplicating the

partial pressure of carbon dioxid in the manner suggested in this paper it should be entirely practicable to obtain a measurement of the H-ion concentration identical with that of the soil in the field. Russell and Appleyard (*10*) have found that the carbon-dioxid content of the soil atmosphere under different conditions varied between 0.02 and 2 per cent, the general mean of arable soils being 0.25 per cent. If these percentages of carbon dioxid are to be regarded as typical for field soils, then in view of the present experiments the changes in carbon-dioxid content during sampling and laboratory manipulation would not invalidate our inferences with regard to the reaction of soils under natural conditions.

The a priori considerations already presented in the first portion of this paper with respect to the effect of carbon dioxid on the reaction of soils are entirely substantiated by the experimental data, which lead to conclusions at variance with those of MacIntire (*8*) on this point. Even saturating the soil suspension with carbon dioxid previous to measuring the reaction did not decrease the H-ion concentration. Therefore it follows that an acid soil would never present to the plant a soil solution of alkaline reaction, notwithstanding any increase in the partial pressure of carbon dioxid. It should be recalled that the criteria heretofore used for judging the reaction of soils do not always permit of an accurate distinction between soils of different reactions. Some soils may be judged as acid from the standpoint of certain lime requirement methods, when in reality their reaction may be alkaline. For this reason it may be doubted whether some of the soils reported as yielding alkaline extracts were in fact acid. Although in certain instances the application of lime may be followed by an increased crop yield, this result may not be dependent upon any change in the reaction of the soil due to the addition of lime. The more accurate interpretation of liming experiments demands that an attempt be made to differentiate lime as a neutralizer of acidity and the other directly or indirectly beneficial effects of lime on the soil or the plant.

The statement frequently met in the literature that the extracts from soils considered acid have a neutral or alkaline reaction has led to the conclusion that water-soluble acids are not found in acid soils. We desire to emphasize again the point that extracts of acid soils, especially those prepared with carbonated water, might become neutral or alkaline after the loss of carbon dioxid from the extract. Moreover the reported results on the extracts are likely to be misinterpreted, for they do not take into account the H-ion concentration but are based upon titrations, using indicators whose end points may be removed from neutrality by several magnitudes. Indeed Gillespie (*3*) has found that soils determined to be acid by the hydrogen electrode, yield extracts whose reactions, colorimetrically estimated, were in close agreement with the hydrogen-electrode measurements.

One of Bouyoucos's (*1*) conclusions from his valuable and ingenious application of the freezing-point method to soil investigations is as follows:

> Since no mineral soil out of a great number tested gave an acid curve but only an absorption curve, and inasmuch as the free acid, and acid salt produced in these soils when they were treated with neutral salts, or acid and acid salts, were carried away by washing and the soils then gave an absorption curve, the conclusion seems to be that the presence of soluble acids, or acid salts, in the mineral soils under favorable natural conditions is only temporary, if ever present, and never permanent. The acidity or lime requirement of soils, therefore, seems to be due mainly to the insoluble acids of the soil, the silicic acid, silica, acid alumino-silicates, and perhaps to the insoluble organic matter. There appears to be then practically no active acidity in the mineral soils, but only negative. Exceptions to these general statements are probably very few.

Contrary to the above conclusion, the data presented in this and other papers (*3*, *11*), show that the solution in equilibrium with the soil particles of certain soils contains H ions in excess of OH ions. Such soils are therefore necessarily acid and they include various types, many of which would be called mineral soils. Furthermore, it is well to bear in mind that the hydrogen electrode is capable of measuring specifically the H-ion concentration, while the freezing-point method is unsuited to this purpose. This is especially true in dealing with such heterogeneous systems as those of the soil mass. These statements are not to be construed as denying the possible value of the freezing-point method in estimating the total "lime requirement."

The soil acids are frequently referred to as insoluble, but such insolubility is, as a matter of fact, only relative, for complete insolubility is practically unknown and the soil acids must therefore have a definite solubility although it may be slight. The important consideration is that the solution of an acid soil must be continuously acid in just the same way that a solution in contact with silicic acid or other slightly soluble acids is always acid. It is quite true that when the soil is treated with a base in order to bring about a condition of alkalinity, by far the greater part of the base is used in combining with acids which at any given moment were not in the solution. But this is in no way opposed to the conclusion that the solution in contact with an acid soil is an acid solution and would accordingly offer an acid medium for plant growth. The effect of such a medium would be related to its H-ion concentration and not to the total quantity of base required to neutralize all the soil acids present. In other words, the reaction of a soil is concerned with the dissolved fraction, which is in equilibrium with the undissolved soil mass. If any added substance—for example, calcium carbonate—disturbs this equilibrium, then it is clear that the undissolved portion of the soil will enter into the reaction in accordance with the laws of mass action.

EFFECT OF POTASSIUM CHLORID ON THE H-ION CONCENTRATION OF SOILS

As previously shown, neutral salts added to suspensions of certain soils considerably increased their H-ion concentration. This fact has brought up the question as to the effect of the diffusion of potassium chlorid from the agar connecting tube into the soil suspension. In order to determine the magnitude of the possible changes induced in the reaction of soil suspensions by the escape of potassium chlorid into them, several experiments were undertaken. For this purpose it was necessary to eliminate as far as possible the diffusion of potassium chlorid into the soil suspension. As shown in Table II, one procedure consisted in bringing the soil suspension into equilibrium with hydrogen without any possible chance for contamination with potassium chlorid, then the electromotive force was read just as the agar tube touched the suspension, thus reducing the diffusion of the potassium chlorid to a minimum. This reading was then compared with subsequent readings made in the manner heretofore described. In addition, some agar tubes prepared with soil extracts were substituted for the potassium chlorid tubes. The sensitivity of our galvanometer did not allow of a greater accuracy than 0.02 volt when the soil-extract tubes were used.

TABLE II.—*Effect of potassium chlorid on the reaction of soil suspensions*

Laboratory number of soil.	With first contact of potassium chlorid tube.		After many contacts of potassium chlorid tube.		Soil-extract tube.	
	Readings on voltmeter.	H-ion concentration.	Readings on voltmeter.	H-ion concentration.	Readings on voltmeter.	H-ion concentration.
		Gram-molecules per liter.		*Gram-molecules per liter.*		*Gram-molecules per liter.*
7	0.681	0.11×10^{-5}	0.664	0.21×10^{-5}	0.661	0.23×10^{-5}
25	.....	.....	.764	$.38\times10^{-7}$	.771	$.29\times10^{-7}$
1	.595	$.33\times10^{-4}$	.589	$.40\times10^{-4}$	.....	.....
26	.677	$.12\times10^{-5}$	.675	$.13\times10^{-5}$	.....	.....
27	.653	$.32\times10^{-5}$	.651	$.35\times10^{-5}$	.....	.....
28	.678	$.12\times10^{-5}$	.675	$.13\times10^{-5}$	.....	.....
29	.702	$.46\times10^{-6}$	.699	$.51\times10^{-6}$	.....	.....
31	.610	$.18\times10^{-4}$	.608	$.19\times10^{-4}$	.....	.....
32	.739	1.0×10^{-7}	.738	$.11\times10^{-6}$	.....	.....
33	.660	$.24\times10^{-5}$	.660	$.24\times10^{-5}$	.....	.....
34	.653	$.33\times10^{-5}$	.653	$.33\times10^{-5}$	.....	.....

It is evident from the data in Table II that the slight diffusion of potassium chlorid from the agar tube has a tendency to increase the H-ion concentration of the soil suspension. In almost all cases this increase corresponds to less than 0.005 volt. For most agricultural purposes this difference has no significance. By bringing the entire system into equilibrium with hydrogen before immersing the agar tube and by keeping the tube out of the suspension except momentarily at the time of reading the electromotive force, it is believed that the error will be entirely negligible.

SUMMARY

(1) The H-ion concentrations of soil suspensions have been measured under various partial pressures of carbon dioxid.

(2) The H-ion concentration of suspensions of acid soils is not markedly affected by increasing the content of carbon dioxid up to 10 per cent. The H-ion concentration of slightly alkaline soils is slightly increased by such treatments. A notable increase in H-ion concentration is observed when soils containing alkali carbonates are similarly treated.

(3) It has not been found that any treatment with carbon dioxid can produce an alkaline reaction in the suspension of an acid soil.

(4) When the original conditions are restored, no permanent change in soil reaction could be attributed to the carbon dioxid.

(5) Further experiments with the hydrogen electrode have confirmed the point of view that solutions in equilibrium with acid soils contain H ion in excess of OH ion.

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